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# Residential construction, land use and the environment. Simulations for the Netherlands using a GIS-based land use model

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The present generation of geographical information systems supports strategic planning processes in several ways. They are able to store, manage and analyse the enormous amount of data needed. Another more output-oriented use is the visualisation of the diversity of locational preferences and perspectives of different interest groups and stakeholders. For the simulation of (more indirect) effects of autonomous or planned developments land use modelling can be applied. A step further is the definition and implementation of a set of indicators that show the impact of land use change on different aspects of space and the environment in order to facilitate the (political) discussions, that are an essential part of strategic planning.

This paper focuses on the application of a GIS-based simulation model in the framework of the Fifth National Physical Planning Report in the Netherlands. The simulation model generates future land use in the Netherlands given several growth scenarios and a spatial strategy that comprises both foreseen strategic and autonomous developments. Special attention is paid to residential construction because this is expected to be one of the major driving forces in land use changes. An analysis of residential construction for the period 1980–1995 reveals that residential construction has been relatively concentrated in areas close to existing urban areas. New town policies also played a rather strong role during this period. The presence of natural areas (woods and wetlands) plays a significant though limited role in the choice where to build new dwellings. The simulation results for the year 2020 are used to assess the effects of land use changes for a range of environmental indicators.

## 1. Introduction

Spatial planning has returned to the forefront of public and politic attention. In Europe this is illustrated by the recent adoption of the European Spatial Development Perspective (ESDP) at the Ministerial conference in Tampere. At the regional and national level numerous examples can be given such as the release of the (first) Regional Plan for Lisbon Metropolitan Area (PROTALM) in Portugal and the Fifth National Physical Planning Report in the Netherlands.

Spatial or physical planning can be seen as a strategic spatial policy aimed at finding the optimum adjustment of space and society. Often the solutions generated by the parties involved, who all have different interests, objectives and preferences, do not lead to satisfactory results. Therefore, governments are often involved in the planning process that is described by Healey [1] as a set of governance practices for the development and implementation of spatial strategies, plans, policies and projects by regulating the location, timing and form of development. These practices are shaped by the dynamics of economic and social change, which give rise to demands of space.

The present generation of geographical information systems (GIS) is used to support these strategic planning processes in different ways. Their ability to store, manage, retrieve and visualise the enormous amount of data regarding spatial objects needed in the planning process is often applied (e.g., [2]). Also spatial analytical functions to assess relevant spatial patterns are widely used. Another development is the linkage of GIS with location or allocation models and more recently the integration of accessible computer based applications or Decision Support Systems.

Various model approaches can be distinguished in the field of land use (cf. [3]):

1. *Planning models.* These models compute an optimal allocation of land in order to arrive at a maximum value for some optimisation criterion (for example, maximum profit of a farm), or to maximise some social welfare objective strived after by a public sector planner (see, e.g., [4]).
2. *Individual choice models.* These models describe the locational preferences of individual actors on the basis of individual decision process [5].
3. *Al-models* derived from the field of Artificial Intelligence. Examples of these allocation algorithms are Neural Networks (NN), Genetic Algorithms and Cellular Automata (CA). Applications of Al-models in the field of allocation planning are, e.g., described in [6–9].
4. *Equilibrium models* explaining land use in terms of supply, demand and equilibrium prices. These models are part of the tradition of the classical approaches of Von Thunen, Losch and Alonso. In most of these models transport and accessibility play an important role as determinants of the equilibrium outcomes of land use. Ex-

amples of operational models used in planning contexts are those of Anas [10] and Landis [11].

In this paper we will use make use of a model of the latter category.

An interesting development is that these land use models are linked to environmental models in order to be able to assess the environmental consequences of land use change (for a review see [12]. For example, changes in land use will have consequences for spatial interaction patterns and these, in turn, will have an impact on emission and noise caused by transport (see also [13]).

This paper focuses on the application of a GIS-based land use model to the Fifth National Physical Planning Report in the Netherlands. The model generates future land use in the Netherlands given several growth scenarios and a spatial strategy that comprises both foreseen strategic and autonomous developments. The simulation results, a map with residential areas and an integrated land use map, are used to assess the effects of land use changes on a wide range of environmental indicators. We focus on land use for residential purposes because this is a very dynamic land use category in the Netherlands. In terms of modelling, most attention will be paid to the Land Use Scanner, a GIS-based model for the Netherlands. Models assessing land use implications for the environment will only be discussed briefly.

The structure of the paper is as follows. We start with a short review of the backgrounds of physical planning in the Netherlands and of possible changes in external conditions (section 2). The land use scanner model is presented in more detail in section 3. Changes in land use for residential purposes during the period 1980–1995 are analysed in section 4. This is followed by a simulation of future patterns in residential construction in section 5. Environmental impacts are analysed in section 6.

## 2. Background of the study

The Netherlands is among the most densely populated countries in the world. Given the high externalities that occur in land use, it is no surprise that the government is quite active in interfering with the land market. Especially in decisions on the location of residential areas the government plays a strong role. The long run national policies on land use are formulated in strategic policy memoranda, the last of which appeared in 1988. The next document called the Fifth National Physical Planning Report will be published in 2000. In the preparatory phase the National Institute of Public Health and Environment (RIVM) analysed basic uncertainties for the future by means of scenarios. Possible consequences for land use and the environment during the period 1995–2020 (the Fifth Report's time span) were investigated.

Aim of the study is not to deliver a blueprint for land use in 2020, nor to simply quantify the impacts of land use change on the environment, but to establish a objectified methodology making use of models to enable discussions on future land use developments. Of course, the discussions can embrace the necessary operational assumptions made in order to obtain results and can also be used to gain understanding of land use dynamics and (indirect) effects on the environment. The main goal, however, is to enable the evaluation of spatial policies and to assess the environmental effects of alternative spatial policies.

### *2.1. Scenarios*

An important element that shapes spatial planning practices is the expected rise or decline in demand for space that results from the dynamics in economic and social change. In order to cope with the uncertainties of future demands for space the concept of scenarios is often used [14]. In this study three internally consistent and coherent scenarios, developed by The Dutch Central Planning Bureau [15], are used to describe demographic, economic, social and policy developments until 2020. These scenarios can be characterised as follows.

- Divided Europe (DE): protectionistic tendencies in the different European countries are strong. Economic growth is low with an annual rise in BNP of approx. 1.7%. The population grows to 16.3 million while the number of dwellings rises to 7.5 million (currently 15 and 6.2 million, respectively). The Common Agricultural Policy (CAP) is continued.
- European Co-ordination (EC): The world economy is dominated by trade organisations resulting in an accelerated integration of the European countries. The annual economic growth is moderate (3.0%) but the growth in population to a total of 17.7 million is the highest of all scenarios. The number of dwellings grows to 7.8 million. A unified European policy is implemented implying a certain level of protection of agriculture in the common market.
- Global Competition (GC): Market forces dominate the world economy and the economic growth is high (3.3%). The number of inhabitants rises to 16.9 million. However, due to a more individualistic life style the number of dwellings grows to 8.1 million, faster than in the EC scenario. The CAP is abandoned forcing the agricultural sector to compete on the world market.

Taking the developments described in the CPB scenarios as a starting point different sector-specific models are used to calculate the amount of land needed for agriculture, housing, industrial and commercial areas in each of the scenarios. The results are shown in figure 1.

The demands for nature and (rail and motorway) infrastructure in the Netherlands are determined by policies that have already been agreed, so that the claims of these land use types are identical in each of the scenarios. Nature (including forest) is also the land use type that claims the largest amount of land until 2020 in each of the scenarios. While the claims for housing, industry and commerce are less than that for nature, they also vary due to the difference in foreseen dwellings and economic growth within

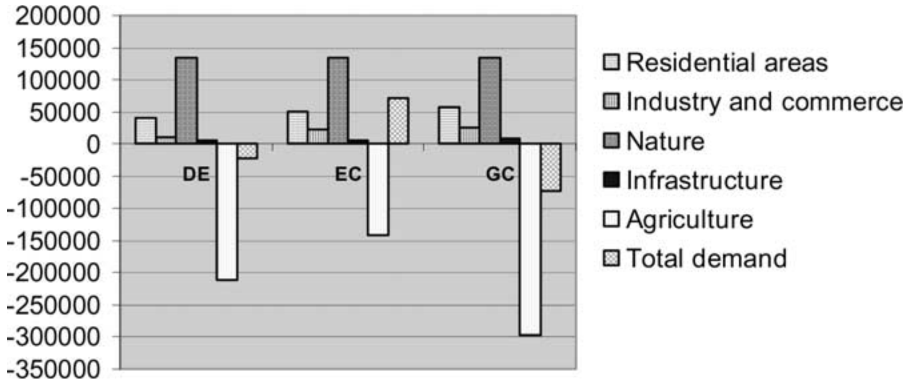


Figure 1. Sectoral land use demands in the three scenarios.

the scenarios. In all scenarios the area used for agriculture declines, only the rate differs in each scenario; high in the Divided Europe and Global Competition scenarios and low in European Coordination. For the Netherlands this results in a surplus of land in the GC scenario and a more or less balanced situation in the DE-scenario. In the EC scenario a situation is reached where the demand for land exceeds the supply by 46000 ha. This calls for a reconsideration of the claims computed by the sectoral models. An integrated analysis of demand for land across various land use types is necessary to arrive at such a conclusion. Such an integrated analysis will be the subject of the next section. The model to be used for this purpose is the LAND USE SCANNER and it will be discussed in the next section.

## 3. The LAND USE SCANNER model

### 3.1. General features

We start with a short characterisation of the properties of the LAND USE SCANNER. Some characteristic features of the model are:

- *Grid based*. The model describes for all grids in a system the relative proportions of land to be used for a number of land use types. Model specification and software allow large numbers of grids. The present version covers 193,399 grid cells of 500 by 500 meters each, covering all of the Netherlands.
- *Integrated*. The model provides an integration framework for sectoral data bases and sectoral policy proposals by confronting these inputs in a spatial-analytical context.
- *Exhaustive*. The model is exhaustive in the sense that all grids in a spatial unit (in our case a country) are considered. All types of land use are explicitly considered; thus there are no "rest" categories left untreated. The model can be formulated in such a way that transfers of wet grids (sea, lakes) into land are allowed.
- *Dynamic*. The model deals with changes in land use taking into account present land use patterns. The suitabilities of the grids for certain types of land use are not assumed constant, but may change as the result of changes in land use in the course of time.
- *Satellite structure*. The model is driven by forecasts at a national or regional level in terms of variables such as population, agricultural production, infrastructure, etc.
- *Stochastic*. The outcomes of the model are to be interpreted as expected proportions of land to be used for various types of land use categories. The use of the model is not that it predicts land use in particular small grids in the future. The main use of the model is that it gives the implications for the spatial patterns of land use of processes such as population growth, production (manufacturing, agriculture, etc.), and natural conservation.
- *Policy oriented*. Several types of sectoral policies have strong spatial implications. LAND USE SCANNER makes these implications explicit. The model helps solving questions referring to the types of grids in which major policy conflicts can be expected to emerge. It can also be used to investigate the implications of sectoral and macro policies for human settlement and land use patterns.

The property of integration means that the LAND USE SCANNER can function as a tool to improve communication between analysts working in various fields of land use (for example, urban functions versus agriculture versus natural land use). The model also helps to improve consistency between projections made in these fields. Thus a potential use of the LAND USE SCANNER is that is does not only function as a modelling tool, but also as a communication tool between analysts in various policy fields.

The following types of land use are distinguished in the present version of the model:

1. Urban: residential, industrial, roads, railways, and airports.
2. Agriculture: pasture, corn, arable land (potatoes, beets, cereals), flower bulbs, orchards, cultivation under glass, and other agriculture.
3. Natural areas: wood, nature.
4. Water.

We arrive at 15 different land use types. This number of land use types can be extended. Data are available for more finely meshed distinctions, thus leading to up to 40 land use categories.

### 3.2. Regional constraints, suitability maps and government interventions

The LAND USE SCANNER model is driven by outcomes of other sector specific models which generate results at a much lower spatial detail. The outcomes relate to the year 2020. The projections for agricultural land use and urban functions have been made for the various scenarios mentioned in the preceding section. Thus, a check has to be conducted to ensure consistency of inputs (see below).

Projections of demand for land at the regional level are available among others for various types of agriculture are available for agricultural regions, of which there are 14 in the Netherlands. For residential and industrial areas projections are given at the level of so-called COROP regions. There are 40 COROP regions in the Netherlands. For natural areas regional constraints are included for 66 regions. The constraints imply that the total amount of land used by nature must be at least the amount which is set as a minimum amount for each region in government plans.

The demand side of the land market is represented by suitability maps. A suitability map is generated for each land use type to indicate the suitability of each grid cell for that type. These suitability maps can be interpreted as bid-prices. The suitabilities depend on factors such as:

- soil quality,
- transition costs, given previous land use,
- accessibility of facilities and infrastructure,
- amount of similar land use in the neighbourhood.

In Hilferink and Rietveld [16] more details are given about the computation of suitability maps.

In addition to suitabilities expressing bid prices of market actors, governmental planning regulations have an impact on land use developments. These include:

- policies towards building permits for residential and industrial land use,
- policies regarding the preservation and development of natural areas.

These policy interventions can be interpreted as subsidies and taxes for certain types of land use so that the final market outcome does not merely reflect the willingness to pay of actors at the market. Also the intentions of the public sector to stimulate or discourage land use of particular types are to some extent reflected by the resulting land use patterns.

### 3.3. Mathematical formulation

A core variable of the model is the suitability $s_{cj}$ for land use of type $j$ in grid cell $c$. This suitability represents the net benefits (benefits minus costs) of land use type $j$ in cell $c$. The higher the suitability for land use type $j$, the higher the probability $x_{cj}$ that the cell will be used for this type. In the simplest version of our model we use a logit type approach to determine this probability:

$$x_{cj} = \frac{\exp(\beta \cdot s_{cj})}{\sum_j \exp(\beta \cdot s_{cj})} \quad \text{for all } c \text{ and } j. \tag{1}$$

Thus, when $\beta$ is zero, all types of land use have the same probability; i.e., the suitability factors $s_{cj}$ do not play any role in determining these shares. On the other hand, when $\beta$ goes to infinite, the limit of probability that the category with the highest suitability gets the cell is equal to 1.

In terms of expected values, the expected volume of land use $L_{cj}$ for category $j$ in cell $c$ equals:

$$L_{cj} = x_{cj} \cdot L_c \quad \text{for all } c \text{ and } j, \tag{2}$$

where $L_c$ denotes the total volume of land in cell $c$. With equally sized cells $L_c$ would of course be equal for all $c$. Unequally sized cells may occur in the case of cells located near the national border, or cells being partly water (if a transfer from water to non-water land use is not allowed), or contain preset land use based on exogenous data, such as infrastructure developments.

The model as formulated here does not guarantee that the allocation of space across possible land uses is in accordance with overall demand conditions. Therefore, side constraints have to be imposed in order to ensure that at the relevant levels of aggregation total demand is met.

This leads to a reformulation of the model. Let $D_j$ be a restriction on total demand for land use category $j$. In addition, let $M_{cj}$ denote the expected amount of land in cell $c$ that will be used for category $j$ taking into account the side constraints. We then arrive at a doubly constrained model:

$$M_{cj} = a_j \cdot b_c \cdot \exp \beta \cdot s_{cj} \quad \text{for the constrained } j \text{ and all } c, \tag{3}$$

where $a_j$ and $b_c$ are balancing factors such that the following constraints are satisfied:

$$\sum_c M_{cj} = D_j \quad \text{for the constrained } j, \tag{4}$$

$$\sum_j M_{cj} = L_c \quad \text{for all } c. \tag{5}$$

Equation (4) guarantees that the expected amount of land allocated for land use type $j$ equals the imposed amount $D_j$. In addition, equation (5) implies that the sum of the expected volumes of the various land use types per cell is equal to the total area of each cell. We use the expression "for the constrained $j$" when an *aggregate constraint* has been formulated for the particular land use type $j$. It is clear that the constraints may imply that no feasible solution exists. This can be checked by seeking for a starting solution of the system in a linear programming context. When no feasible solution is found, the aggregate constraints have to be reconsidered before the model can be used. For those land use types $j$ for which no *aggregate constraint* applies we arrive at:

$$M_{cj} = b_c \cdot \exp \beta \cdot s_{cj} \quad \text{for unconstrained } j \text{ and all } c \quad (3')$$

under constraint (5) so that we may conclude that in this case $a_j$ has been set equal to 1. Note that in the extreme case that none of the land use types has any *aggregate constraints*, we have $M_{cj} = L_{cj}$ for all $c$ and $j$, and $b_c = L_c / \sum_j \exp(\beta \cdot s_{cj})$ for all $c$.

### 3.4. Balancing factors

The above reformulation as a doubly constrained land use model is helpful for an understanding of the structure of the model. The structure of the model is quite similar to doubly constrained spatial interaction models used in transportation research (see, for example, [17]). We now turn to the interpretation of the balancing factors. From equations (3)–(5) it follows that:

$$b_c = \frac{L_c}{\sum_j a_j \cdot \exp(\beta \cdot s_{cj})} \quad \text{for all } c, \quad (6a)$$

$$a_j = \frac{D_j}{\sum_c b_c \cdot \exp(\beta \cdot s_{cj})} \quad \text{for the constrained } j, \quad (6b)$$

$$a_j = 1 \quad \text{for the other } j. \quad (6c)$$

$\sum_c b_c \cdot \exp(\beta \cdot s_{cj})$ can be interpreted as the aggregate suitability of land for land use type $j$; when the suitability of land use type $j$ would be low in terms of $s_{cj}$, the value of the denominator in (6b) is low as well. The balancing factor $a_j$ is high when a high constraint $D_j$ is combined with a low aggregate suitability.

In a similar way $\sum_j a_j \cdot \exp(\beta \cdot s_{cj})$ in (6a) can be interpreted as a measure of demand for land use in cell $c$. A high value of this expression means that the demand for the land in cell $c$ for the various land use types (taking into account the urgency of the land use types as represented by $a_j$) is relatively high. It leads to a low value of the balancing factor $b_c$, and thus ensures that in equation (5) the total amount of land finally allocated in cell $c$ does not exceed the supply of available land $L_c$. Thus, the solution of the doubly constrained model yields as a side-product the shadow prices of land in the cells. Another way to interpret the balancing factors is to rewrite equation (3) as:

$$M_{cj} = \exp\left(\beta \cdot \left[s_{cj} + \beta^{-1} \cdot \log(a_j) + \beta^{-1} \cdot \log(b_c)\right]\right) \quad \text{for the constrained } j \text{ and all } c. \quad (3'')$$

A large value of $a_j$ implies a strong pressure on land use type $j$. It can be interpreted as a subsidy to this type of land use; the subsidy is given to ensure that the aggregate target for land use type $j$ is achieved. The reverse case is a small value for $a_j$; this can be interpreted as a tax on this land use type to prevent that excess of the related target. Note that the case in between occurs when $a_j$ equals 1, implying $\log(a_j) = 0$.

In order to clarify the role of the balancing factors, we perform the following transformation on (3″). Define land use price $p_c$ in cell $c$ as $-(1/\beta) \cdot \log(b_c)$ and price $\lambda_j$ for constraint $j$ as $+(1/\beta) \cdot \log(a_j)$, now $M_{cj}$ can be considered as a demand function of land use price $p_c$

$$M_{cj}(p_c) = \exp(\beta \cdot s_{cj} + \lambda_j - p_c). \quad (3''')$$

This formulation also sheds light on the $b_c$ factor. A high value of $b_c$ means that use of cell $c$ is discouraged. It can therefore be interpreted as an indicator of demand/supply conditions in each cell.

An increase in the aggregate demand of category $j$ will lead to a shift in land use in the following way. The higher value of $D_j$ will lead to a higher balancing factor $a_j$, which will lead to a corresponding increase in the expected land use in the various grids depending on the relative suitability of the grids for the various types of land use.

### 3.5. Extensions to the doubly constrained land use model

In reality the model is more complex than presented here. One complication is that the constraints are not always in terms of equalities, but in terms of inequalities. Consider the constraint that:

$$\sum_c M_{cj} \geqslant D_j. \quad (4')$$

Then in the case when the constraint is not binding, we have $a_j = 1$, and when the constraint is binding we have $a_j$ as defined in (6b). Thus, in this case we arrive at:

$$a_j = \max\left\{1, \frac{D_j}{\sum_c b_c \cdot \exp(\beta \cdot s_{cj})}\right\} \quad \text{for all lower bounded } j. \quad (7)$$

In the case of an $\geqslant$ constraint we arrive at:

$$a_j = \min\left\{1, \frac{D_j}{\sum_c b_c \cdot \exp(\beta \cdot s_{cj})}\right\} \quad \text{for all upper bounded } j. \quad (8)$$

Another complication is that the aggregate constraints not only function at the level of the country, but also at various regional levels. This means, for example, that population predictions have been made for labour market regions, or that agricultural production has been predicted at the level of agricultural areas. This leads to an extended version of the model where the balancing factor $a_j$ becomes specific for each region for which a constraint has been formulated.

Solution of the model is done in an iterative way. In the case of equality constraints, it only boils down to finding the values of $a_j$ and $b_c$ in equations (6a)–(6c).

Beginning with arbitrary values for the $a_j$, one can compute the resulting values for $b_c$ by means of (6a). Then these $b_c$ values are fed into equation (6b) leading to revised values for $a_j$.

In the case where some of the constraints are in terms of inequalities, one should use equations (7) and (8) instead of (6b). Once these factors have been determined, the implied land use pattern can easily be found by means of equation (3).

### 3.6. Interpretation in terms of market equilibria

In section 1 we indicated that the land use scanner model belongs to the class of equilibrium models. Equilibrium takes place at the macro-level: aggregate supply for land is given (it is assumed to be inelastic) and aggregate demand for land for various land use types is also given at the level of regions. Inequality constraints (see equation (4′)) ensure that aggregate demand does not exceed aggregate supply. Prices do not play a role at the aggregate level in the present version of the model since both demand and supply are price inelastic at this level. Future development of the model may lead to the specification of elastic demand functions at the aggregate level.

Also at the level of individual cells demand and supply of land are in equilibrium (see equation (5)). Balancing factors are used to achieve this. These balancing factors can be interpreted in terms of shadow prices (see (3′′′)). Cells with high suitability for various types of land use will have a high shadow price to ensure that demand does not exceed supply. Note, for example, that in (3′′′) the shadow price $p_c$ functions as a correction factor for a high level of suitability $s_{cj}$.

## 4. An analysis of changes in residential land use 1980–1995

In this section we discuss the estimation of suitability indicators for housing. This will be done for the period 1980–1995. In the next section the outcomes of this estimation will be used for a simulation during the period 1995–2020. Residential construction in the Netherlands is subject to two main forces: the preferences of the residents and the directions of the national and regional governments. Especially in the Western part of the country the government plays an important role by commanding residential construction at certain new town and by discouraging urban sprawl. It is impossible to separate the two driving forces. This means that the estimations of determinants of residential construction reflect a mixture of private sector preferences and public sector objectives.

The data on which the estimations are based relate to the growth of the housing stock in grids. We consider the space available for residential construction in 1980 in each grid cell as a starting point. Since we consider only open space the possibilities for residential construction within urban areas are low. The dependent variable in the analysis is the share of available land in each that is ultimately used for residential construction. For details on the estimation procedure we refer to Wagtendonk and Rietveld [18]. The following types of factors are assumed to play a role in the attractiveness of residential location:

- accessibility of work locations,
- proximity of other residential areas,
- accessibility of natural areas,
- distance to highway access points and to railway stations,
- presence of highways and railway lines in a grid.

The accessibility of *work locations* is taken into account by computing for each grid cell the weighed sum of the number of jobs in the grids until a distance of 60 km. For the weights distance decay factors are used that have been calibrated for commuting trips. Accessibility indicators have been computed for various types of jobs. It appears that these are highly correlated, implying a multi-collinearity problem. Therefore it does not make sense to include accessibility for several types of jobs in the same regression.

*Proximity to other residential areas* is used to reflect preferences of residents to live in places where there is sufficient supply of urban facilities and the public sector objective to prevent urban sprawl. The latter means that residential construction is stimulated to take place in a spatially concentrated form: in open spaces within urban areas and near existing residential areas. This variable is measured by computing for each grid cell the total area used for residential purposes in the 8 contiguous grids. A related indicator is the introduction of a *dummy for new towns* in those grids where the national government has planned the location of a new town.

*Accessibility of natural areas* is included to take into account the natural values in the surroundings of grids. For each grid cell the surfaces of forest areas and wetlands within a circle of 15 km are computed. These surfaces are weighted by means of distance decay factors in a similar way as with the accessibility of jobs.

As a negative indicator of the quality of the natural environment in a grid cell we introduce the *presence of infrastructure* (highways and railway lines). We expect that the noise problems involved will discourage developers to build residences in such a grid. Of course, infrastructure also yields accessibility, but this is not necessarily correlated with the presence of these infrastructures in a grid, because they depend more in particular on the location of highway access points and railway stations. This is reflected by the next indicator.

*Distance to highway access points and to railway stations*. These variables are measured via the distance to the nearest highway access point and the nearest railway station. They are general indicators of the appreciation of consumers to live at locations that offer them easy access to high quality transport networks.

The analysis has been carried out for two types of dwellings (one dwelling houses and multiple dwelling houses). The multiple dwelling houses are mainly found in urban areas. Another distinction used is the one between the most urbanised area (Randstad Holland) and the rest of the country. The reason is that in the former part the degree of government intervention is much higher. Thus we arrive at four different segments for which estimations have been carried out. The results are summarised in table 1.

We find that in Randstad accessibility of jobs did not play a role for one dwelling houses. A possible explanation is that within this highly urbanised area accessibility of jobs

Table 1
Parameters of the four regression equations that explain the location of new residential areas over the period 1980–1993.

| | One dwelling house | | | | Multiple dwelling house | | | |
|---|---|---|---|---|---|---|---|---|
| | Randstad Holand | | Other regions | | Randstad Holand | | Other regions | |
| | $B$ | $T$-value | $B$ | $T$-value | $B$ | $T$-value | $B$ | $T$-value |
| Intercept | –7.02 | –389.6 | –20.35 | –255.6 | –11.81 | –462.2 | –15.02 | –329.8 |
| Industry | not applicable | | not applicable | | 0.28 | 121.4 | not applicable | |
| Knowledge services | not applicable | | 1.00 | 160.0 | not applicable | | 0.34 | 79.3 |
| Forest for leisure purposes | –0.02 | –27.5 | 0.06 | 36.0 | 0.04 | 39.9 | not applicable | |
| Wetlands | not applicable | | not applicable | | 0.07 | 69.1 | 0.11 | 39.6 |
| Highways | –0.34 | –94.7 | –0.36 | –69.6 | –0.11 | –42.5 | –0.15 | –27.0 |
| Railways | –0.58 | –91.3 | 0.05 | 7.0 | –0.37 | –85.1 | –0.30 | –35.8 |
| Highway accesses | 0.04 | 33.0 | 0.12 | 61.3 | –0.12 | –117.2 | not applicable | |
| Railway stations | –0.14 | –103.5 | –0.12 | –87.4 | 0.05 | 56.6 | –0.18 | –109.7 |
| Growth centers | 1.13 | 264.0 | 0.74 | 101.0 | 1.63 | 366.0 | 1.08 | 121.6 |
| One-family dwellings | 0.73 | 548.0 | 0.54 | 242.1 | 0.83 | 934.1 | 0.88 | 300.8 |
| Multiple-family dwellings | 0.06 | 75.7 | 0.39 | 331.7 | 0.10 | 126.0 | 0.50 | 328.7 |
| Pseudo $R^2$ | 0.67 | | 0.59 | | 0.41 | | 0.50 | |

is high anywhere so that a negligible impact results. For the other three market segments considered the accessibility of jobs did play a role in residential construction during the period considered. Accessibility of wetlands and forest areas appears to play a role in all market segments: with one exception we find that residential construction is stimulated by the presence of natural areas in the region. Also the other environmental indicators (presence of highways and railways) have the expected signs. In grid cells where these infrastructures are present the probability that open land will be converted into residential use is smaller than in other regions. Distances to railway stations tend to have a negative impact on the probability of residential construction in a zone. This can partly be explained by governmental policies to stimulate residential construction near railway stations. As indicated by Rietveld [19] such a policy of building near railway stations certainly makes sense given the importance of non-motorised transport modes as access modes to the railway network. For highways distance does not play such a clear role as a determinant of residential construction.

Spatial patterns of existing dwellings have a very strong impact on residential construction. Table 1 shows for all market segments that new residences tend to be built in the immediate neighbourhood of existing residential areas. In addition to existing residential areas new towns appear to play an important role in residential construction between 1980 and 1995. For all market segments the assignment of a new town (or growth centre) status has led to a strong increase in residential construction in the grid cells concerned.

## 5. Simulation of future land use

Based on estimates of suitabilities for various types of land use and on national and regional totals for certain types of land we have simulated the developments of future land use. We start with a discussion of land for residential purposes.

### *5.1. Residential land use*

The pattern illustrated by figure 2 underlines the strong position of the current large cities in the Netherlands (Amsterdam, Rotterdam, The Hague and Utrecht) in the Central and Western part of the country. Given the concentration of work locations in these areas it is here where the highest probabilities can be found that open space is used for the construction of new housing. In addition, there is a considerable number of medium sized cities that appear to be attractive locations for residential activities. A difference between single and multiple family dwellings is that the latter are expected to be much more concentrated in the urban areas. This makes sense given the higher land prices, the smaller household size and the lower income levels usually observed in urban areas in the Netherlands.

Part of figure 2 is based on government plans in physical planning that have been formulated in earlier stages and that have not yet been implemented, but where the realisation is (almost) sure. Another part of figure 2 is based on the model parameters estimated in table 1. This means that we assume that the parameters estimated for the period between 1980 and 1995 also hold for the period after it. For example, we assume that the role of the attraction of proximity to work locations in residential construction remains unchanged during the periods considered. Other assumptions could of course have been formulated. For example, one might conjecture that proximity to work locations becomes less important in view of the potential of ICT induced telecommuting. We have abstained from such a broad analysis of possible futures. Thus the results presented here are based on the assumption that preferences of physical planners, real estate developers and public sector remain unchanged. The only

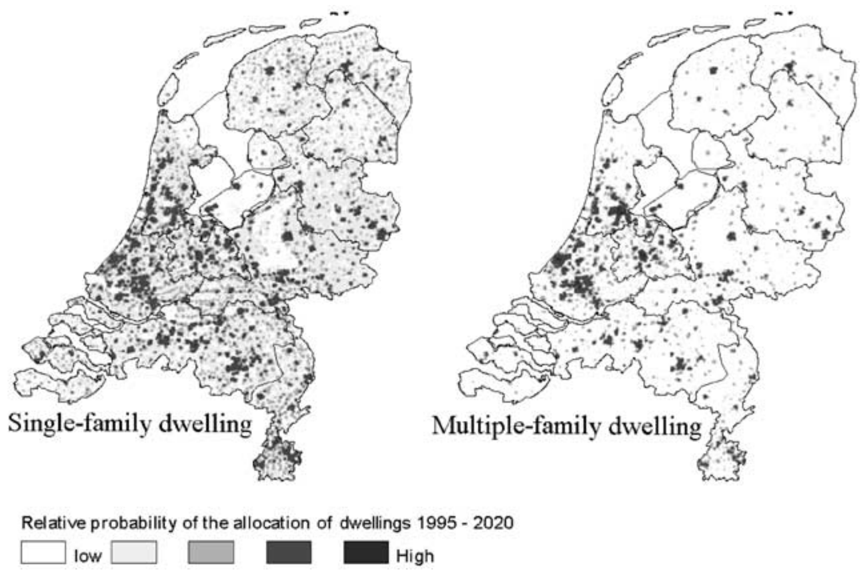


Figure 2. Regression based probabilities of the allocation of one and more-family dwellings for the period 1995–2020.

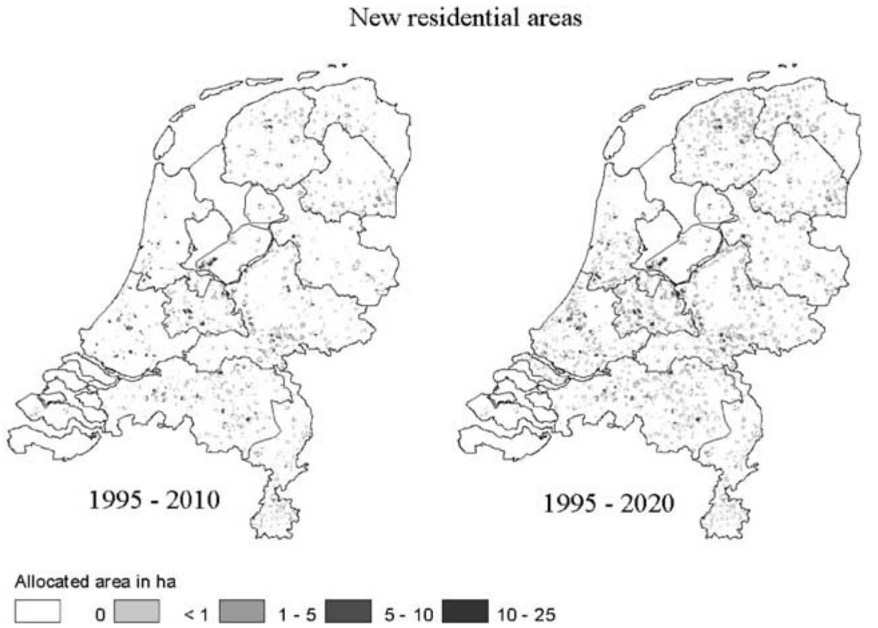


Figure 3. Location of the new residential areas simulated for the period 1995–2010 and 1995–2020 according to the EC scenario.

uncertainties considered in the present paper relate to the elements of the scenarios (see section 3).

On the basis of figure 2 one can derive predictions of the extent to which zones will experience a change into land use for residential purposes. The results are presented in figure 3 for the CE scenario. This means that population is assumed to increase from 15.5 million in 1995 to 17.7 million in 2020. All provinces except for the province of Zealand (located in the South West) are expected to experience major expansion of residential areas. Most expansion is expected to take place in the vicinity of the present cities plus in a very limited number of new towns. For the other scenarios maps with similar patterns result. The scenarios do not so much differ in terms of spatial development patterns but more in terms of speed of expansion of the area used for residential purposes.

A striking difference between figures 2 and 3 is that in figure 2 the existing major urban areas can easily be identified, whereas they remain invisible in figure 3. The reason is that figure 2 demonstrates the probability that land can be used for residential construction *assuming that it is open land*. Since most of the land in the urban areas is already used for urban activities it plays only a small role in the reallocation of land for residential use as shown in figure 3. Figure 3 shows that open areas rather close to the existing cities are expected to dominate residential construction.[1]

[1] Thus, figure 3 is most relevant when one is interested in *absolute* changes in land use, whereas figure 2 represents *relative* changes in landuse.

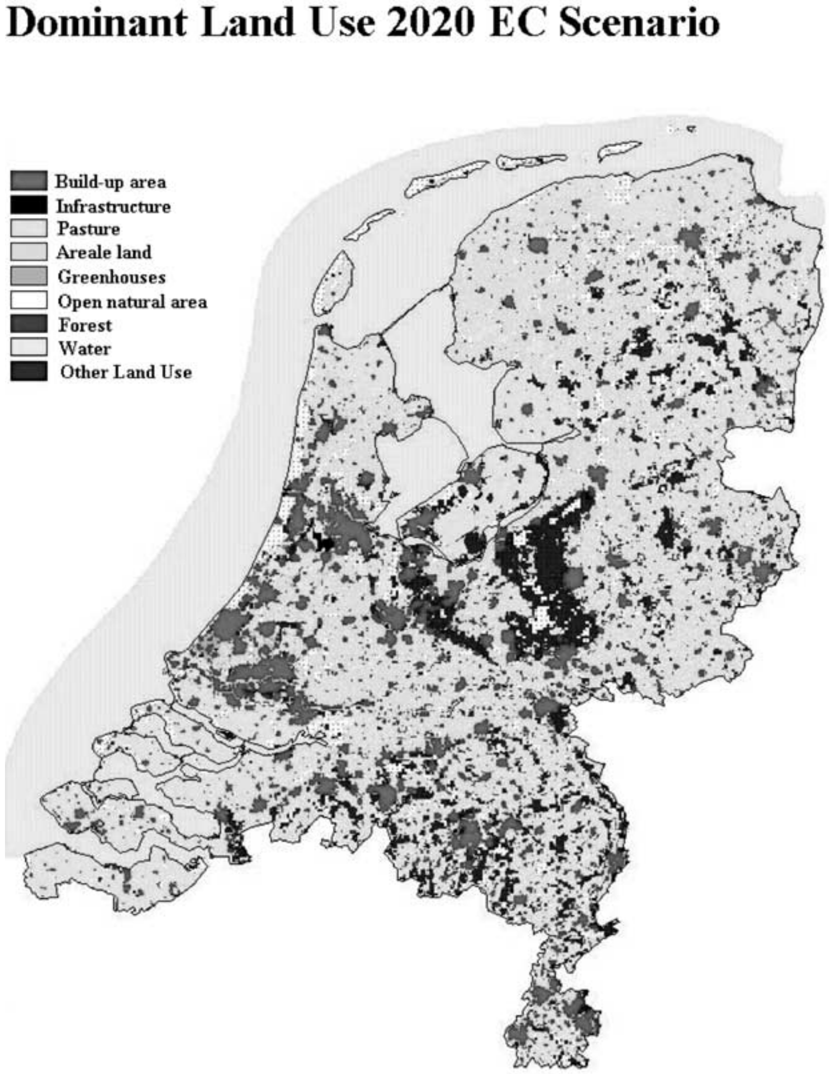


Figure 4. Integrated land use map 2020 for the Economic Co-ordination scenario, existing spatial planning policies and autonomous developments.

### *5.2. Integrated land use map*

In the above analysis we have focussed on changes in land use in view of shifts towards residential purposes. In order to present a more complete picture on changes in land use we briefly discuss the way these land use types have been taken into account in the Land Use Scanner. The land use types distinguished have already been mentioned in section 3.

In the sections above we have already discussed he claims for residential land use based on the suitabilities estimated in section 5, and driven by the projected national population total according to the various scenarios. In addition to these claims for residential land use various projections have been used for other land use types such as industrial and commercial areas, infrastructure, leisure areas, water and natural areas, each driven by their own national or regional constraints. Agriculture appears the main land use type that is loosing area. The integrated land use map for 2020 that is the result of applying the above procedure is presented in figure 4 for the EC scenario.

## 6. Environmental impact assessment

The results derived above have been used to determine the effects of land use change on the environment my means of a set of indicators. The indicators have been selected on the basis of political relevance, sensitivity for land use change, the broad coverage of environmental themes and the availability of operational models. Some of the indicators can be directly computed by means of the Land Use Scanner model. However, in most cases land use as predicted for 2020 (generated with the Land Use Scanner model) is just only one of the essential inputs to compute the relevant indicators. Due to the broad coverage of the environmental themes these indicators are calculated using knowledge and a wide range of models available at the RIVM and other institutes.[2] We give some details for a selection of indicators.

The expansion of nature as delimited by the provinces will increase the area of nature in the Netherlands significantly. However, spatial analysis shows that the locations of

[2] Important contributions were made by Alterra and AVV.

new natural areas are so scattered that the cohesion of natural areas develops in a less favourable way than the increase in natural area. The quality of the flora in the Netherlands is calculated with the Nature planner model. The value of the indicator is a product of nature quantity and the nature quality expressed as the occurrence of selected plant species [20]. The increase in nature quality can be preliminary contributed to the restoration of the ground water levels. Reduction in acidification and fertilisation are too small to have a significant influence.

Spatial analyses regarding safety show that new built up areas are located in areas in danger of flooding and water excess, taking into account the water drainage in 2020. While other land use types like natural areas are also not planned at locations were they can have a reducing effect on flooding and water excess.

The model FACTS [21] is used to calculate the ownership, fuel cost and energy use of passenger cars in 2020. Car ownership and fuel cost are, in conjunction with the Land Use Scanner results, used to calculate the use of cars on an average working day making use of the LMS-Model [22]. The outputs of the LMS model are on their part again used to calculate the noise nuisance (making use of the model described in [23] and the accessibility of jobs by the labour force with a commuting time lower than 45 minutes [24].

The overall conclusion of the comparison between the present situation and the simulation for 2020 is that the environmental quality is improving, although one has to keep in mind that currently implemented policies without spatial aspects also have positive impacts on the environmental quality in the year 2020. Especially the indicators dealing with nature are positive owing to the realisation of more than 150,000 hectares of new nature. This is about 4% of the total area of the country and implies a considerable shift in land use. The background of this increase is that agricultural areas are replaced by natural areas. Not only the total size of natural areas is improving, also the cohesion of natural areas is getting better. Cohesion is measured in terms of the degree to which the cutting up of natural areas has been avoided. It is an important qualitative aspect of nature since in addition to total area also the existence of barriers between natural areas has an impact on ecosystems.

The environmental indicators show that an increase in $CO_2$ emissions is expected. The improvement of energy efficiency of cars is more than off-set by an increase in car use and an increase in the weight of cars. The amount of nitrate that leaches to groundwater, and threatens its use for drinking water, decreases.

The new housing developments have a negative impact on the landscape indicators. Even though new residential areas tend to be built near to existing residential areas there is a tendency that the openness of landscapes (measured via the extent to which built areas interfere with open space) deteriorates. Another aspect of the expected residential construction activities is that in vulnerable regions in the Netherlands the flooding hazard and the chance on water excess increases moderately.

## 7. Concluding remarks

The analytical possibilities of geographical information systems have been improved substantially by linking them to land use models. This enables planners to assess the pro's and con's of various spatial principles or to value the effects of spatial strategies on policy targets or societal aims. Moreover, it opens the way to a much more quantitative approach to planning that can complement the present more qualitative planning practice.

This study shows that it is possible to anticipate complex land use dynamics and their environmental impacts. Due to the developments in the IT world in general and the world of Geographic Information Systems in particular the problems encountered are no longer technological. When the central objective is to support decision makers the main concerns are to ensure that the numerous different models involved make use of the same validated data and that the quality and limitations of intermediate results are known to those researchers that use them for further processing.

The simulated land use dynamics, which form the final result of a complex allocation methodology, give an explanatory overview of the locational preferences of the selected land use types and their mutual interactions. It is recommended that auxiliary information regarding demand for land, suitability maps, etc. is also made available to the decision maker(s) involved in strategic planning. This does not only help to gain insight in the driving forces that affect land use but may also support the formulation of alternative spatial strategies.

An interesting conclusion from section 6 is that during the period from 1995 to 2020 there is substantial scope for improvement for the size of natural areas in the Netherlands, even though the population is expected to increase with about 15% and total area claimed for urban activities increases substantially. The reason is that there is still sufficient area from agriculture that can be converted into natural areas or into urban area. The results for the quality of the local environment are mixed. On the one hand pollution of ground water and ammonia deposition are expected to improve. However, according to indicators related to quieting of landscape, openness of landscape and historical values of landscape will deteriorate. Therefore a challenging theme for future research and policy is to broaden the issue of conservation or expansion of natural areas to the more general theme of the improvement of qualities of landscapes.

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